CHAPTER 16

Cross-Site Synthesis of Complexity in Coupled Human and Natural Systems

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16.1 Introduction

Coupled human and natural systems (CHANS) are integrated systems in which human and natural components, including wildlife, interact with each other (Liu et al., 2007a; Chapter 2). Previous chapters (Chapters 3–14) have extensively explored complex human–nature interactions in a single coupled system—Wolong Nature Reserve—from numerous angles and by integrating information from multiple disciplines. Nonetheless, to reach even broader and more generalizable insights about the dynamics of coupled systems, findings from site-specific coupled system studies in different ecological, socioeconomic, political, demographic, and cultural settings should be synthesized (Acevedo et al., 2008, Carter et al., 2014a, Liu et al., 2007a, Parker et al., 2003, Rindfuss et al., 2008, Turner et al., 2003). Such cross-site syntheses can facilitate knowledge exchange among researchers, managers, policy makers, and local residents, and enhance their capacity to address conservation and sustainability challenges in coupled systems around the world.

As such, in this chapter we apply what we have learned about the coupled system in Wolong Nature Reserve (hereafter Wolong) to understand another complex coupled system in Chitwan National Park (hereafter Chitwan) in Nepal. This application is facilitated by the fact that studies on human–wildlife interactions in Chitwan were inspired by those in Wolong (Carter et al., 2014a). We chose to investigate Chitwan because it has several commonalities with Wolong but also provides a different local context to help illustrate the diversity of coupled systems. Like Wolong, Chitwan is a "flagship" protected area within a global biodiversity hotspot (Myers et al., 2000). Similar to the way in which Wolong supports the giant panda (*Ailuropoda melanoleuca*), Chitwan supports another important wildlife population—the tiger (*Panthera tigris*). Both species are globally endangered conservation icons. Like Wolong, long-term empirical, interdisciplinary data exist for Chitwan, giving us a more holistic perspective of the various interconnections between components of coupled systems. The interactions between people and nature, institutional arrangements, and socioeconomic and demographic changes at both sites are also very similar to those in many other coupled systems around the world (Frost and Bond, 2008). Here, we take a comparative approach to discussing several key features of coupled systems occurring across both sites. Many important patterns and processes observed in Chitwan would have been missed had an integrated approach not been used. Further, we highlight several lessons learned that may be useful for fostering human–wildlife coexistence not only in China and Nepal but also in many other places (Chapron et al., 2014).

16.2 The homes of two wildlife conservation icons

Information about the home of giant pandas, Wolong Nature Reserve, is provided in Chapter 3 and many other previous chapters. Below we briefly describe the home of the tiger.

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Chitwan National Park (Figure 16.1), established in 1973, comprises an area of 1,000 km^2 and is situated in Chitwan District at the base of the Himalayas in Nepal. It was initially established to protect a rapidly diminishing population of the one-horned rhino, but it is now also a globally important region for the conservation of the tiger (Sanderson et al., 2006). The park has one of the largest wild populations of tigers (~125 adults) in South Asia (Karki et al., 2013). The park also affords protection for many other endangered species such as the gharial crocodile (*Gavialis gangeticus*), gaur (*Bos gaurus*), and Indian rock python (*Python molurus*). Chitwan's climate is subtropical. A summer monsoon occurs from mid-June to late September, followed by a cool, dry winter. Average annual rainfall is 240 cm, 90% of which falls during the summer monsoon. Temperatures peak (maximum 38°C) during the monsoon and drop to a low of 6°C afterward (October to January; Laurie, 1982). Chitwan ranges in elevation from 150 m to 815 m. Natural forests include moist deciduous forests dominated by Sal (*Shorea robusta*), with some mixed deciduous/evergreen forests mainly along river banks (i.e., riverine). Other natural land-cover types include grasslands (e.g., wooded grasslands, phantas, and floodplain grasslands; Carter et al., 2013).

Like Wolong, local livelihoods in Chitwan are primarily based on subsistence agriculture with dependence on forest resources (Table 16.1). Unlike Wolong, however, no one lives inside Chitwan National Park. In 2011, the human population living adjacent to the park was approximately 550 000 local residents in over 130 000 households (Nepal Central Bureau of Statistics, 2012). Many of those residents adjacent to the park use resources inside the park. From the perspective of resource use, there is little difference from residents inside Wolong. As in Wolong, household activities such as forest conversion to cropland and livestock grazing

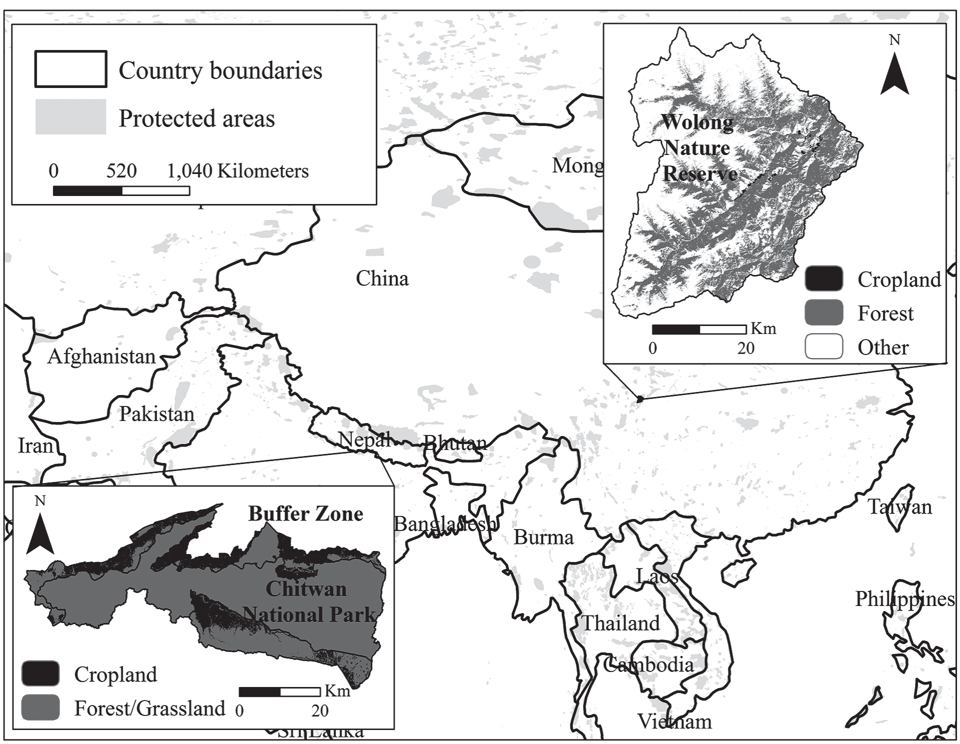

Figure 16.1 Locations and major land-cover types of the two focal systems: Wolong Nature Reserve in China and Chitwan National Park in Nepal.

Table 16.1 Major features of key components in coupled human and natural systems in Wolong, China, and Chitwan, Nepal.

Components	Major features	Wolong (China)	Chitwan (Nepal)
Local residents	Main crops	Cabbage, maize, potatoes, turnips	Rice, maize, wheat, mustard, lentils
	Main livestock	Cattle, goats, horses, yaks, pigs, chickens	Buffalo, goats, chickens
	Timber and non-timber forest products	Timber, fuelwood, fodder, medicinal herbs	Timber, fuelwood, fodder, thatch, medicinal herbs
	Sources of off-farm income	Tourism, wage labor, labor migration, commercial businesses	Tourism, wage labor, labor migration, commercial businesses
Forests	Major land-cover classes	Mainly coniferous forest, deciduous broad leaf forest, mixed deciduous-coniferous forest, grassland above the tree line	Deciduous forest (e.g., Sal forest), mixed deciduous and evergreen forest (e.g., riverine forest), grassland (mostly in river banks)
Wildlife	Endangered charismatic megafauna	Giant panda, golden monkey, takin, snow leopard	Bengal tiger, one-horned rhino, wild elephant, gharial crocodile, gaur, leopard
Policies	Conservation policies	Resource extraction bans in nature reserve, Natural Forest Conservation Program (collective forest monitoring), Grain to Green Program	Resource extraction bans in national park, grass-cutting program, community forest comanagement in buffer zone
Contextual factors	Macrolevel socioeconomics	Opportunities for tourism, off-farm jobs, access to markets, infrastructure	Opportunities for tourism, off-farm jobs, access to markets, infrastructure

in forests negatively affect tiger habitat and behavior (Carter et al., 2013, 2012a). Hunting pandas and tigers in both sites, now illegal, was more common in the past (Hu, 1989, Nowell, 2012). Although diminished, tiger hunting in Chitwan continues to be a constant threat given their small population size (Chapron et al., 2008). Tigers, like pandas, increasingly provide economic benefits to local residents through tourism rather than through hunting (Liu et al., 2012, Spiteri and Nepal, 2008). Tourism benefits thus provide a rationale for panda and tiger conservation. However, residents in both Wolong and Chitwan can incur the indirect costs of conservation. Examples include constraints on resource use and increased crop predation by growing numbers of other wild animals such as wild boars. The latter occurs because conservation and restoration of habitats for pandas and tigers are also good for many other wild animals (Liu et al., 1999a). In addition, residents in Chitwan can incur significant direct costs associated with tiger conservation, such as tiger attacks on livestock and people (Gurung et al., 2008). It is clear that fostering long-term coexistence in both sites necessitates a holistic understanding of how people and wildlife are interconnected.

16.3 The complexity of coupled systems

The components of coupled systems (see examples in Table 16.1) form complex webs of interactions. As a result, coupled systems are characterized by features of complex systems. Examples include reciprocal interactions and feedback loops, non-linear relations and thresholds, surprises, heterogeneity, telecoupling (Chapters 2 and 17), vulnerability, and time lags and legacy effects (Liu et al., 2007a, b, 2013a; Chapters 2, 13, and 17). In this section, we integrate findings across the two coupled systems with respect to each of these features (examples shown in Table 16.2), with an emphasis on impacts on pandas and tigers.

16.3.1 Reciprocal interactions and feedback loops

In coupled systems, people and nature interact reciprocally. As such, the effects of human activities on forests and wildlife often generate feedback loops that affect humans and their activities (Liu et al., 2007b). For example, the growth and expansion of natural resource-dependent human

Table 16.2 Examples of complexity features for coupled human and natural systems in Wolong Nature Reserve in China and Chitwan National Park in Nepal. For definitions of each feature, see Table 2.1.

Complexity features	Examples in Wolong (China)	Examples in Chitwan (Nepal)
Reciprocal interactions and feedback loops	People collect fuelwood → degrade panda habitat → people go farther to collect fuelwood → increases area of panda habitat loss.	Forest conservation policies → more tigers → more tiger–human conflicts → possibly lose local support of conservation policies.
Non-linearity and thresholds	Collection of fuelwood up to 1,800 m from household decreases area of panda habitat, though impact is negligible beyond 1,800 m.	Tolerance to impacts from tigers (e.g., livestock depredation and attacks on people) has thresholds, beyond which people may kill tigers.
Surprises	Loss of panda habitat increased after the reserve was established due to synergistic effects of factors such as human population growth, household proliferation, and increased tourism.	Grazing restrictions increased tiger prey numbers in park's buffer zone but also likely increased negative human–tiger interactions because people more frequently enter forests to collect fodder for stall-fed livestock.
Heterogeneity	Household locations and resource consumption activities vary in different parts of the reserve.	Household locations, being outside park, and resource consumption activities differ across space.
Embedment and telecoupling	Local residents migrate out of Wolong to find employment in other areas, and often send remittances back home.	Chitwan is located on a transit route and is a point of origin for poached tigers, whose parts are sold on the international black market.
Vulnerability	Earthquake in 2008 caused severe landslides, disrupted agricultural trade and tourism, and reduced panda habitat.	Nepal civil war (1996–2006) displaced local residents and increased poaching of tigers.
Time lags and legacy effects	Past logging locations affect current forest type and panda habitat quality.	Past migration policies affect spatial patterns of human activities (e.g., land use) with respect to tiger habitat.

communities in both sites are strongly linked to declines in panda and tiger habitats and population sizes (Axinn et al., 2010, Axinn and Ghimire, 2011, Chen et al., 2010, Matthews et al., 2000, Tuanmu et al., 2011). However, as forests and grasslands shrink, they become more distant from households. This spatial shift makes the extraction of timber and non-timber forest products more difficult and more time-consuming (Axinn and Ghimire, 2011, He et al., 2009). In Chitwan, such changes reciprocally influence human population parameters, including childbearing and migration, which in turn, exert different effects on wildlife habitat. For example, increasing costs and time in collecting forest products are linked to larger households. Couples facing such challenges have more children to help collect forest resources to support the household (Biddlecom et al., 2005, Liu et al., 1999b, c). Each additional birth places more pressure on vegetation and thus wildlife habitat (Axinn and Ghimire, 2011, Linderman et al., 2006). This phenomenon is an example of a positive feedback loop. In contrast, less access to fuelwood and fodder increases the difficulties of an agricultural lifestyle. Such challenges may cause people to find a different means of living such as ecotourism or move somewhere else for jobs through rural–urban migration (Chen et al., 2012, Massey et al., 2010). These trends have occurred in both sites. This phenomenon is an example of a negative feedback loop.

Policies are key feedback mechanisms (Chapter 13). In Wolong and Chitwan, degradation of forests and wildlife habitat prompted policy makers to develop and implement new policies (Adhikari, 2002, Liu et al., 2001, Nagendra et al., 2008, Viña et al., 2007). Policies can change human activities, both directly and indirectly. Direct changes may include preventing timber extraction and fuelwood collection or spurring tree planting. Indirect changes may include incentives to use alternatives to fuelwood, such as electricity and natural gas (Entwisle et al., 1996, Homewood et al., 2001, Li et al., 2013, Liu et al., 2005). For instance, to counter the loss of panda habitat, and to restore forests for other benefits (e.g., reduction in soil erosion), two major national conservation programs began in Wolong in

2000 and 2001 (see also Chapter 13). The Grain to Green Program (GTGP) provides cash, grain, and tree seedlings to farmers if they return cropland to forest (Chen et al., 2009, Liu et al., 2008). The Natural Forest Conservation Program (NFCP) bans logging and provides cash for households and communities to monitor forests to prevent illegal harvesting (Chen et al., 2014; see also Chapter 13). The implementation of these conservation policies has reversed a more than 30-year trend of panda habitat degradation in the reserve (Viña et al., 2007, 2011; see also Chapter 7).

Similarly, to reduce local resentment toward the exclusion policies of Chitwan National Park, a "grass-cutting" program was initiated in 1976. This program allows local residents to legally enter the park for a limited number of days each year to collect thatch grass, reeds, rope bark, and rope grass (Stræde and Helles, 2000). Furthermore, to mitigate human pressure on Chitwan's forests, a buffer zone (~750 km^2) surrounding the park was created in 1996 with the goal of restoring ecosystem integrity while also improving human livelihoods. Approximately 30–50% of the park's annual revenue from tourism must be invested in the buffer zone for community development programs (Government of Nepal, 1993). Examples include alternative income opportunities and infrastructure improvement. Furthermore, livestock grazing was prohibited in the buffer zone forests. In addition, resource management responsibility for several forest tracts was devolved to local community user groups (Gurung et al., 2008, Nagendra et al., 2005). These forest conservation policies likely enabled forests outside Chitwan National Park to support greater densities of wild prey animals and provide better coverage for tigers (Carter et al., 2013). As a result, tiger habitat quality improved from 1999 to 2009 after the implementation of those policies (Figure 16.2).

However, as the positive effects of conservation policies in both coupled systems become manifest, unanticipated feedbacks such as human–wildlife conflicts are also emerging. For example, the increase in forest cover in Wolong has caused an increase in native wildlife that raid cropland (Yang et al., 2013). In Chitwan, forest recovery is supporting greater numbers of tigers (Barlow et al., 2009). This increase in tigers has resulted in an increase of attacks on people (Carter et al., 2012b). For example, 65 local residents were killed from 1998 to 2006 compared to 6 from 1989 to 1997 (Gurung et al., 2008). A feedback occurs when the crop/livestock losses or human attacks become too great. Local residents may be driven to further participate in off-farm economic activities, such as wage labor opportunities in the cities. Residents may also decide to abandon farming altogether, a phenomenon we saw occurring in both sites.

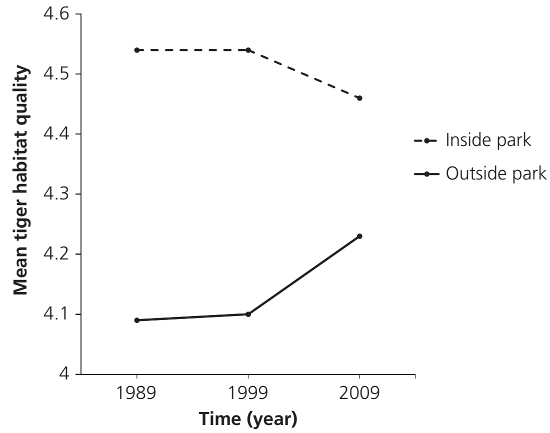

Figure 16.2 Mean tiger habitat quality inside and outside the northern portion of Chitwan National Park in 1989, 1999, and 2009. Tiger habitat quality decreased inside the park from 1999 to 2009, while it increased outside the park over the same time period. The increase in habitat quality outside the park was likely due to forest conservation policies, such as the prohibition of livestock grazing and community forestry, which were implemented in the late 1990s. Data from Carter et al. (2013).

16.3.2 Non-linearity and thresholds

Multiple and reciprocal interactions within a coupled system typically result in non-linear relationships between and among its components. For instance, changes in household-level fertility patterns occur, such as the interval between successive births and the age at which a woman has her first child (Chapter 8). These changes have non-linear effects on the number of households in a given area. Simulation results indicate that fuelwood consumption resulting from such changes in household numbers, in turn, has a non-linear effect on panda habitat over time (Dussault et al., 2005).

A specific yet common type of non-linear relationship is a threshold or tipping point, beyond which one state or regime abruptly changes to another (Liu et al., 2007a). For instance, human effects on wildlife may exceed a threshold, after which wildlife habitat or behavior alters drastically. In Wolong, the distance between household and fuelwood collection site has a threshold effect on panda habitat (Dussault et al., 2005). The area of panda habitat is negatively related to the distance between household and fuelwood collection site until that distance reaches approximately 1800 m (Figure 16.3A). Beyond that distance, the area of panda habitat stabilizes because the impacts of fuelwood collection on forest and bamboo (the main food source for the panda) become sparsely distributed. In Chitwan, a similar threshold appears at approximately 600 m from the human-settled area (Figure 16.3B).

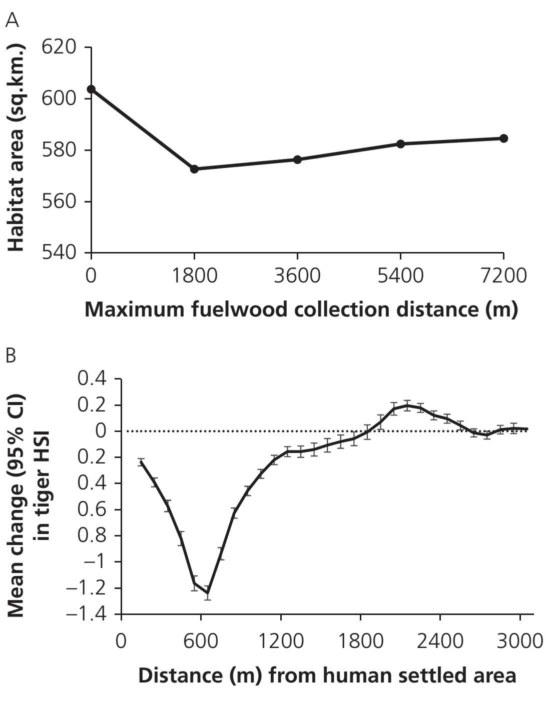

Figure 16.3 (A) Example of threshold (1,800 m) where effect of distance between household and fuelwood collection location on panda habitat in Wolong changes. Source: adapted from An et al. (2005). Reprinted by permission of the Association of American Geographers. (B) Change in Bengal tiger estimated habitat suitability index (HSI) in the 1990s with distance from human-settled areas inside the northern portion of Chitwan National Park, Nepal. Source: adapted from Carter et al. (2013).

The effect of wildlife on people also exhibits thresholds. For example, in Chitwan, local people may tolerate tiger-related risks to a certain degree. But when that tolerance threshold is exceeded, they will likely take action to reduce the threat to human livelihood or safety (Slovic, 1987). As a result, poisoning or poaching of tigers may suddenly occur when it had not occurred in the past, although this has not yet been empirically detected.

16.3.3 Surprises

When coupled systems are not understood, surprising dynamics may occur, with negative consequences for wildlife and their habitat. For instance, panda habitat degraded faster inside Wolong after the reserve was established even though the reserve was expressly designed to protect panda habitat from degradation (Liu et al., 2001). In part, this was due to the human population inside the reserve, mostly of minority ethnicities and thus not encumbered by the one-child policy, continuing to increase after the reserve was established. In addition, between 1975 and 2012, the number of people inside Wolong Nature Reserve increased by 92% but the number of households increased by 241% (Chapter 8). The tourism industry also grew substantially, leading local people to use more fuelwood to produce marketable goods. The synergistic effects of population growth, household proliferation, and tourism catalyzed the surprising decline in panda habitat detailed in Chapter 7 (Liu et al., 2001). As with Wolong, household proliferation in Chitwan appears to be strongly linked to environmental degradation (Carter et al., 2013). From 1991 to 2011, the number of people in Chitwan District increased 64% but the number of households increased by 103% (Nepal Central Bureau of Statistics, 2012). These changes perhaps contributed to a decreasing trend in tiger habitat suitability inside the park over the same period (Figure 16.2; Carter et al., 2013).

Exclusion policies in Wolong and Chitwan also have led to surprising changes in human livelihoods, particularly with respect to livestock numbers and husbandry, which have impacts on panda and tiger habitats. As access to fodder has become increasingly difficult in Wolong, local residents purchased more horses and let them range freely inside the reserve. As Chapter 4 showed, pandas avoided free-ranging herds of horses inside the reserve. Horses may disturb important panda behaviors such as feeding (grazing for food), mating, and raising young (Hull et al., 2011, 2014). In Chitwan, restrictions on livestock grazing have had different consequences from those in Wolong. To adjust to changes in grazing policies, households in Chitwan have reduced their holdings of large livestock, like buffalo, in favor of goats (Gurung et al., 2009). Households also now stall feed their livestock comparatively more than they did in the past when they could let the livestock range freely in the forests. As such, the direct impact of livestock on forest cover and structure is less than in the past. Nonetheless, fodder collection is now more common, which increases the likelihood of tiger attacks on people (Gurung et al., 2009).

The exact reasons for the difference in response to grazing restrictions between Wolong and Chitwan have yet to be determined. However, it is likely related to the respective balance of costs and benefits associated with holding free-ranging livestock in both sites. For instance, maintaining free-ranging livestock may be easier in Wolong. There, people are already living inside the reserve, natural livestock predators are not common, and the cost of collecting fodder by hand is quite high due to the mountainous topography. In contrast, goat milk and meat are highly valuable in Chitwan while the traction benefits of water buffalo are growing less important as mechanized farm equipment becomes more common and agricultural landholding per household decreases over time. Surprising patterns and divergence in livestock husbandry practices stemming from changes in policies and socioeconomic conditions were evident in both Wolong and Chitwan. These patterns and their potential effects on pandas and tigers highlight the need to take an integrated approach to studying coupled systems.

16.3.4 Heterogeneity

The number and strength of couplings between human and natural systems vary across spatial, temporal, and organizational scales. Such heterogeneity has implications for wildlife and their habitat. For instance, at a broad spatial scale, dense populations of people and wildlife in both sites generally do not inhabit the exact same areas. Human settlers usually clear forests (and thus destroy tiger and panda habitats) for cultivation. However, at a fine spatial scale along the interface between people and wildlife (e.g., forest–agriculture edge), the story is different. Tigers and pandas are frequently using the same space as people who are entering the forest on foot and vehicles. Tigers and pandas are both naturally shy and elusive. In Chitwan tigers offset their activity patterns to be much less active during the day when human activity (e.g., local residents collecting forest products and tourists on vehicle safaris) peaks (Carter et al., 2012a). Temporal rather than spatial displacement at the fine scale allows tigers to continue using the prey-rich habitats in Chitwan despite the ubiquitous presence of people.

The strength of couplings between human and natural systems also varies over time. For instance, in recent years, local people in both Wolong and Chitwan have been progressively moving away from agriculture toward off-farm employment. They take jobs in the booming tourism industry and seek wage employment in construction of infrastructure (e.g., buildings and roads; Axinn and Ghimire, 2011, He et al., 2008). Shifts away from agriculture in Wolong and Chitwan likely mean that local residents are less directly dependent on nearby natural resources (e.g. forest products). Less dependence on natural resources lessens the strength of the direct coupling between local residents and natural ecosystems. Over the short term, this decoupling will likely reduce human pressure on panda and tiger habitats; however, it is unclear what the impacts of the decoupling will be in the future. Uncertainty about the long-term effects of dynamic couplings on people and wildlife underscores the urgent need to continue research on coupled systems for long time frames.

The creation of institutions or institutional change also can modify the strength of couplings. Institutional arrangement (e.g., top-down versus bottom-up) with regard to land management policies and practices can have a particularly large effect on wildlife and their habitat. In Wolong and Chitwan, forests are primarily managed by the central government. The Chinese government exerts strict control over the resources extracted from Wolong (including both timber and non-timber forest products). However, forest harvesting still occurs (Liu et al., 2001). Likewise, the Nepalese government controls access to forests within Chitwan National Park, and strictly prohibits natural resource extraction except during a very limited period. Yet illegal collection of forest products in Chitwan occurs throughout the year (Stræde and Treue, 2006). Notably, in state-controlled forests, panda habitat was lost in Wolong and tiger habitat degraded in Chitwan. However, forest management regimes have changed recently in Wolong and Chitwan, with direct implications for wildlife habitat.

In Wolong, NFCP, initiated in 2001, departed from the traditional top-down model. NFCP in Wolong does not rely on state agencies to monitor certain forest parcels for infractions (e.g., illegal logging) but instead devolved those responsibilities to local households. Specifically, monitoring activities of large forest parcels were assigned to groups ranging in size from one to 16 households (Chapter 13). Households received payment from the government for effective protection of the forest parcels. Residents suffer payment reduction if illegal activities (e.g., logging, hunting, mining, or grazing in restricted areas) are detected during the government's biannual field assessments (Yang et al., 2013). Land management regimes have also changed in Chitwan. Management of forested areas outside the park in Chitwan District, which previously were part of the state-controlled national forest system, was handed over to local user-group committees. These committees have responsibility and control over resource use. For instance, committees dictate the amount and times of year that local people can collect or purchase fuelwood, timber, and fodder from community forests (Nagendra et al., 2005). Decentralizing some of the monitoring and land management responsibilities to local institutions in both sites seems to be aiding the recovery of panda and tiger habitats (Carter et al., 2013). This pattern occurs because decentralization can encourage greater participation by those who depend on forests, greater accountability of decision-makers, and stronger enforcement of property rights and governance arrangements (Agrawal et al., 2008).

16.3.5 Telecoupling

The degree to which coupled systems are embedded within other systems (e.g., embedment) or connected with distant systems (e.g., telecoupling, see Chapter 17) also varies. For example, Chitwan is part of a broader international effort to link protected areas along the base of the Himalayas (*Terai*) in India and Nepal through forest corridors (Dinerstein et al., 2007). As a result, conservation interventions that strengthen institutional support for community-managed forestry in "stepping stone" forests between protected areas have been implemented. Additionally, a number of conservation measures have been conducted in priority forest corridors and tracts outside protected areas. These efforts include reducing local reliance on forest products, providing alternative income opportunities for local residents, and raising awareness about the benefits of intact forests and tigers for local communities. This endeavor has modified the way people use forests and interact with tigers, and has helped expand the available land base for tigers, particularly outside protected areas. Similarly, national-level policies in China connect the human and natural systems in Wolong to larger and distant coupled systems. A severe drought in 1997 and catastrophic floods in 1998 affected much of China. These events triggered the development of NFCP and GTGP, which were designed to reduce soil erosion and the likelihood of drought due to poor water retention in soils devoid of vegetation (Liu et al., 2013b). Both programs have modified the connections between people and nature in Wolong, and as described above, have helped restore panda habitat in Wolong.

The movement of people inside and outside of Wolong and Chitwan links those coupled systems to other systems via telecoupling (e.g., socioeconomic and environmental interactions over distances; Liu et al., 2013a). Out-migration physically removes people from the coupled systems, and remittances from migrants connect the coupled systems of Wolong and Chitwan to the broader national and global economies. In general, out-migration and household goods purchased with remittances reduce human pressure on habitat (Chen et al., 2012). Tourism, on the other hand, brings people from around the world into the coupled systems of Wolong and Chitwan. Although tourism does support local livelihoods to an extent, there is concern that tourist activity in the protected areas may disturb pandas and tigers (Curry et al., 2001, Liu and Viña, 2014). Uncontrolled resource collection and development (e.g., building lodges and tea houses) for the sake of the tourist industry depletes forest resources and negatively impacts panda and tiger habitats (Liu et al., 2001, UNEP/WCMC, 2011).

The movement and transport of tigers and pandas to areas outside Chitwan and Wolong, respectively, also connect these coupled systems to other systems. For example, tigers are sometimes poached from Chitwan and trafficked to and sold in black markets in places all over the world, but mainly China. In addition, Chitwan sits on a main transit route for traffickers moving tiger parts over the Himalayas from India to China or elsewhere in the Himalayan region (Nowell, 2012). The trafficking of poached tigers within and across international boundaries is highly illegal and is also enormously lucrative. The trade of wild animals for profit ranks as the world's third-largest (US$20 billion) illicit activity behind drug and weapon smuggling (Wyler and Sheikh, 2008). Pandas, like tigers, are highly sought by zoos all over the world. As such, the panda breeding center in Wolong loans their captive-bred pandas, typically at very high costs, to zoos in other countries (Chapter 17). The selection of zoos for panda visits is entwined in national and international politics. Changes in these two coupled systems due to telecoupling create spillover effects on other coupled systems (Liu et al., 2013a). Examples of these spillover systems include Chengdu in China and Kathmandu in Nepal, both stopovers of wildlife transported from and people traveling to Wolong and Chitwan. Systematic assessments of these spillover systems and explicit consideration of them are important when developing and implementing policies.

16.3.6 Vulnerability

Vulnerability is the likelihood that coupled systems experience harm due to changes in their dynamics from internal or external forces (Liu et al., 2007a). For instance, in Chitwan, the introduction of invasive species from outside the system has altered vegetation composition and structure. Specifically, *Mikania micrantha*, or "mile-a-minute weed," is increasingly common in Chitwan and rapidly grows over and kills vegetation by restricting its access to sunlight. As such, *Mikania* is considered a major and imminent threat to natural ecosystems in Chitwan. In addition, *Mikania* is generally unpalatable to wild ungulates. By killing other palatable plant species for tiger prey species, *Mikania* can have a cascading negative impact on tiger habitat. Invasive species have not yet had this magnitude of impact on panda habitat in Wolong, but managers should be vigilant for future invasions given the impacts seen in Chitwan.

Coupled systems can be vulnerable to natural and anthropogenic events. A strong earthquake in Wolong in 2008 significantly disrupted the coupled systems there (Chapter 12). With respect to the natural system in Wolong, the earthquake caused many severe landslides that have exacerbated flooding in the region and reduced panda habitat (Viña et al., 2010). With respect to the human system, the earthquake destroyed the main road leading into the reserve. This event brought tourism to a halt and severely crippled access to outside markets. The earthquake also forced many people whose homes were destroyed to relocate to other areas inside the reserve (Chapter 12). A different type of disturbance had similar overarching effects in Chitwan. A ten-year-long civil war (1996–2006) took place between the military of the monarchy and an insurgent group with a Maoist political philosophy. This war had direct implications for both the human and natural systems as well as their interactions. Many people were displaced from Chitwan, and people changed their daily activity patterns to avoid potentially dangerous situations. Importantly, enforcement of the National Park rules broke down. Park guards (who belong to the Nepalese army) were removed from the park in order to fight insurgents in other parts of the country. As a result, poaching rates of tigers and rhinos spiked during the civil war (Baral and Heinen, 2005). Additionally, tiger conservation actions organized and led by international conservation agencies were put on hold or halted indefinitely because it was too dangerous in Nepal. These two very different disturbances highlight the vulnerability of coupled systems and demonstrate the profound effects of disturbances on coupled systems. Both resulted in changes that reverberated throughout the entire systems (not just one sector or subsystem), and both caused the systems to enter into a new system state. Although one disturbance was acute and the other sustained, both resulted in long-term vulnerabilities.

Among protected areas, Wolong and Chitwan support large numbers of pandas and tigers relative to other areas; however, the populations of both species in their respective coupled systems are very small in demographic terms. This fact is largely due to habitat fragmentation that occurred in both landscapes (Smith et al., 1998, Viña et al., 2010). Smaller local animal populations are inherently more vulnerable than larger populations to demographic and environmental stochasticity. For instance, genetic drift, inbreeding, and catastrophic losses to disease place smaller populations at a greater risk of extinction than larger populations (Lande, 1993). Thus, human impacts, such as poaching, loss of habitat, and exposure to disease from livestock increase the vulnerability of the small populations of pandas and tigers (Kenney et al., 2014). Life-history characteristics of the animal can also affect their vulnerability. For example, tigers may be more vulnerable to habitat fragmentation than pandas because their home ranges of 20–240 km^2 (Bengal tigers, Goodrich et al., 2010) are several orders of magnitude larger than the 3–10 km^2 occupied by pandas (Hull et al., 2015, Pan et al., 2001, Schaller et al., 1985, Yong et al., 2004, Zhang et al., 2014).

16.3.7 Time lags and legacy effects

The mechanisms linking human and natural systems are also temporal (Chapter 2). Thus, the effects of one component on another may not become apparent until after a certain amount of time, or time lag. In Wolong, simulation results indicate that increasing fertility (number of children) increases the number of households about 20 years later as it takes time for children to mature and establish their own households. Increasing household numbers increases fuelwood consumption and reduces panda habitat in about 30 years (An and Liu, 2010; Chapter 8). A similar relationship between human population processes, household number, resource demand, and tiger habitat degradation likely also occurs in Chitwan, but it has not been empirically demonstrated. A much shorter time lag exists between changes in the prices of electricity or non-wood fuels (e.g., kerosene) and impacts on habitat. If prices for electricity or non-wood fuels rise, people immediately collect more fuelwood to cook with and heat their homes, and thus destroy more habitats (Liu et al., 2007a).

The impacts of forest conservation policies on wildlife habitat also take time to manifest because the process of forest growth is relatively slow. In Chitwan, the effects of different forest management regimes on tiger habitat are only recently becoming apparent. It has been 10–15 years since forests outside the park were handed over to local communities to manage in the late 1990s. In this time, tiger and tiger prey numbers have increased because forest conditions have improved (Carter et al., 2013). In Wolong, time delays in forest recovery after implementation of policies involving local communities (NFCP, GTGP) have been shorter than in Chitwan. Perhaps this difference may be because they involved replanting fast-growing exotic tree plantations. However, the shorter time lag may be offset in the long term due to the inadequacy of the exotic plantations to provide suitable habitat for pandas.

Another temporal feature of coupled systems is legacy effects. Legacy effects are the impacts of past interactions in coupled systems on later conditions (Liu et al., 2007b). For instance, prior to the 1950s, the indigenous Tharu people of Chitwan were sparsely distributed throughout the forests and were subsistence hunters and gatherers. However, hunting was prohibited inside the park once it was established and the large-scale conversion of forest to agriculture starting in the 1950s forced indigenous people to rapidly modify their lifestyles. Thus, the present spatial patterns of land cover and land use, human population distribution, and human activities, all of which affect tigers and their habitat, are the legacy of past policies. Similarly, in Wolong, past logging locations affect current forest type and panda habitat quality. The frequency of pandas using an area is reduced for several decades after harvest of timber (Bearer et al., 2008).

16.4 Some lessons learned

Knowledge about complex human–nature interactions in Wolong helped us explain similarly complex dynamics between people and wildlife in Chitwan. For example, multilevel or multiscalar patterns and processes observed in Wolong helped us understand how similar processes may be at play in Chitwan. In both sites, we found that dynamics at the household level, such as fertility and marriage timing, underlie important aggregate-level patterns, such as the association between habitat loss and household number at the reserve level. Likewise, processes at broad scales, such as regional or global industrialization and urbanization, appear to influence fine-scale behaviors in both sites, such as out-migration of individuals or households. These findings highlight that some processes occurring in coupled human and natural systems are independent of context, a key conclusion that could not be made without cross-site application and synthesis. Such knowledge not only improves our understanding of complex systems more generally, but also informs policy makers on which specific socioeconomic and demographic factors drive changes in wildlife population and habitat dynamics.

Work in Wolong also highlighted the importance of policies as feedback mechanisms, which we observed in Chitwan as well. Considering policies as feedback mechanisms can help managers and policy makers anticipate the potential impacts that may emerge from various policies. Otherwise, conservation policies can have unintended or undesirable consequences. This was the case with Wolong. The synergistic effects of population growth, household proliferation, and tourism led to faster declines in panda habitat after the reserve was established than before (Liu et al., 2001). Likewise, the increase in tiger attacks on people in Chitwan over the last two decades could have been anticipated (and addressed more effectively) if it had been interpreted as a feedback. Such a feedback emerged due to land management policies that occurred outside the park in the mid-1990s.

Similarly, our experience in Wolong indicates that spatial and temporal thresholds are common features, and as such, should be anticipated and accounted for in policy making. The exact point at which the threshold may occur may not always be precisely identified. But simply being aware of an imminent threshold provides rationale for implementing or strengthening policies that better protect panda or tiger habitat or mitigate human–wildlife conflict before the threshold point is crossed. For example, using various policies to proactively increase tolerance among local communities toward tigers may reduce retaliatory killing of tigers likely to occur once tiger attacks on people and livestock exceed a certain threshold (Carter et al., 2014b). An example of how this could be done is by creating conflict response teams comprising local people and government authorities.

Our work also suggests the importance of collaborative management and protection of natural ecosystems. Local people should be partners in the design, implementation, and enforcement of resource management to aid with the recovery of imperiled wildlife. In Wolong (Chapter 7) and in Chitwan's buffer zone, a habitat "transition" from degradation to recovery was observed after institutions implemented policies involving local people in conservation. It is important to note, however, that policies alone may not be enough. Whether conservation policies, especially those developed from outside the focal system, will overlay on preexisting community institutions and networks likely determines the success of those policies (Ostrom et al., 1999). For example, grazing restrictions in Wolong, implemented at the state level, were ignored by many local people in part because grazing livestock was still considered socially acceptable among local communities. In contrast, grazing restrictions were linked with community forestry in the buffer zone outside Chitwan, thus grazing livestock in community forests was very uncommon because it violated community-held norms.

Over the last few decades, the telecoupling processes between Wolong and outside coupled systems have grown in strength and number (Chapter 17). As in Wolong, we found that telecoupling processes, such as tourism and migration, are also growing in strength in Chitwan. Such telecouplings have cascading and complex effects on tigers and people (Carter et al., 2014a). The increasing influences of telecoupling processes on human–wildlife interactions in both sites suggest that a similar trend may be occurring in many coupled systems around the world, with yet unknown and potentially negative consequences on wildlife. Thus, more research on telecoupling processes and their spillover effects on other systems is urgently needed. This gap needs to be addressed to explain telecoupling impacts on wildlife and potential for human–wildlife coexistence not only in Wolong and Chitwan but also many other sites around the world.

Finally, complex features and processes do not occur independently from one another, but rather interact. Moreover, the outcomes of these interactions on human–wildlife coexistence are mediated by local site differences, underscoring the need to understand local context and history in addition to more general features of complex systems. For example, both sites are characterized by vulnerability, legacy effects, and heterogeneity. However, differences in how these features interacted with each other and shaped human–wildlife dynamics in both sites required an understanding of each site's unique land-use, anthropological, and institutional histories. Such information helps reveal why certain policies, such as grazing restrictions, may be more or less successful in seemingly similar sites.

16.5 Summary

Research on coupled human and natural systems has enriched knowledge on how humans and nature interact and how such interactions in turn affect global sustainability. But to move this emerging field forward, more generalizable theories, approaches, and conclusions about human–nature interactions are needed. To this end, intensive research conducted across multiple different model coupled systems needs to be synthesized. In this chapter, we applied what we have learned about human–wildlife interactions in Wolong Nature Reserve in China to understanding complex processes and dynamics in the coupled system in Chitwan National Park in Nepal. Like Wolong, Chitwan is also a "flagship" protected area within a global biodiversity hotspot that supports a globally endangered conservation icon—the tiger (*Panthera tigris*). The interactions among wildlife, institutional arrangements, and socioeconomic and demographic changes at both sites are also similar to those in many other coupled systems around the world. We conducted an in-depth analysis of key properties across the two sites, including reciprocal interactions and feedback loops, non-linear relations and thresholds, surprises, heterogeneity, telecoupling, vulnerability, time lags, and legacy effects. We found similarities and differences across the two sites and discussed what the findings mean for understanding complex human–wildlife systems. For example, in both systems collaborative policies that involved local people were more effective than exclusionary policies that forcibly limited people's activities. Explicating the effects and interactions of complex features on human–wildlife coexistence will only become more pertinent in the future as the world is expected to grow ever more crowded and interconnected.

References

Acevedo, M.F., Baird-Callicott, J., Monticino, M., et al. (2008) Models of natural and human dynamics in forest landscapes: cross-site and cross-cultural synthesis. *Geoforum*, **39**, 846–66.

Adhikari, T.R. (2002) The curse of success. *Habitat Himalaya*, **9**, 1–4.

Agrawal, A., Chhatre, A., and Hardin, R. (2008) Changing governance of the world's forests. *Science*, **320**, 1460–62.

An, L. and Liu, J. (2010) Long-term effects of family planning and other determinants of fertility on population and environment: agent-based modeling evidence from Wolong Nature Reserve, China. *Population and Environment*, **31**, 427–59.

Axinn, W.G., Barber, J.S. and Biddlecom, A.E. (2010) Social organization and the transition from direct to indirect consumption. *Social Science Research*, **39**, 357–68.

Axinn, W.G. and Ghimire, D.J. (2011) Social organization, population, and land use. *American Journal of Sociology*, **117**, 209–58.

Baral, N. and Heinen, J.T. (2005) The Maoist people's war and conservation in Nepal. *Politics and the Life Sciences*, **24**, 2–11.

Barlow, A.C.D., McDougal, C., Smith, J.L.D., et al. (2009) Temporal variation in tiger (*Panthera tigris*) populations and its implications for monitoring. *Journal of Mammalogy*, **90**, 472–78.

Bearer, S., Linderman, M., Huang, J., et al. (2008) Effects of fuelwood collection and timber harvesting on giant panda habitat use. *Biological Conservation*, **141**, 385–93.

Biddlecom, A.E., Axinn, W.G., and Barber, J.S. (2005) Environmental effects on family size preferences and subsequent reproductive behavior in Nepal. *Population and Environment*, **26**, 583–621.

Carter, N.H., Gurung, B., Viña, A., et al. (2013) Assessing spatiotemporal changes in tiger habitat across different land management regimes. *Ecosphere*, **4**: art124.

Carter, N.H., Riley, S.J., and Liu, J. (2012b) Utility of a psychological framework for carnivore conservation. *Oryx*, **46**, 525–35.

Carter, N.H., Riley, S.J., Shortridge, A., et al. (2014b) Spatial assessment of attitudes toward tigers in Nepal. *Ambio*, **43**, 125–37.

Carter, N.H., Shrestha, B.K., Karki, J.B., et al. (2012a) Coexistence between wildlife and humans at fine spatial scales. *Proceedings of the National Academy of Sciences of the United States of America*, **109**, 15360–65.

Carter, N.H., Viña, A., Hull, V., et al. (2014a) Coupled human and natural systems approach to wildlife research and conservation. *Ecology and Society*, **19**, 43.

Chapron, G., Kaczensky, P., Linnell, J.D.C., et al. (2014) Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science*, **346**, 1517–19.

Chapron, G., Miquelle, D.G., Lambert, A., et al. (2008) The impact on tigers of poaching versus prey depletion. *Journal of Applied Ecology*, **45**, 1667–74.

Chen, X., Frank, K.A., Dietz, T., and Liu, J. (2012) Weak ties, labor migration, and environmental impacts toward a sociology of sustainability. *Organization & Environment*, **25**, 3–24.

Chen, X., Lupi, F., He, G., et al. (2009) Factors affecting land reconversion plans following a payment for ecosystem service program. *Biological Conservation*, **142**, 1740–47.

Chen, X., Lupi, F., Viña, A., et al. (2010) Using cost-effective targeting to enhance the efficiency of conservation investments in payments for ecosystem services. *Conservation Biology*, **24**, 1469–78.

Chen, X., Viña, A., Shortridge, A., et al. (2014) Assessing the effectiveness of payments for ecosystem services: an agent-based modeling approach. *Ecology and Society*, **19**, 7.

Curry, B., Moore, W., Bauer, J., et al. (2001) Modelling impacts of wildlife tourism on animal communities: a case study from Royal Chitwan National Park, Nepal. *Journal of Sustainable Tourism*, **9**, 514–29.

Dinerstein, E., Loucks, C., Wikramanayake, E., et al. (2007) The fate of wild tigers. *BioScience*, **57**, 508–14.

Dussault, C., Ouellet, J.-P., Courtois, R., et al. (2005) Linking moose habitat selection to limiting factors. *Ecography*, **28**, 619–28.

Entwisle, B., Rindfuss, R.R., Guilkey, D.K., et al. (1996) Community and contraceptive choice in rural Thailand: a case study of Nang Rong. *Demography*, **33**, 1–11.

Frost, P.G.H. and Bond, I. (2008) The CAMPFIRE programme in Zimbabwe: payments for wildlife services. *Ecological Economics*, **65**, 776–87.

Government of Nepal (1993) Fourth amendment to the national parks and wildlife conservation act (2029). *Nepal Gazette*, **43**(Suppl.).

Goodrich, J.M., Miquelle, D.G., Smirnov, E.N., et al. (2010) Spatial structure of Amur (Siberian) tigers (*Panthera tigris altaica*) on Sikhote-Alin Biosphere Zapovednik, Russia. *Journal of Mammalogy*, **91**, 737–48.

Gurung, B., Nelson, K.C., and Smith, J.L.D. (2009) Impact of grazing restrictions on livestock composition and husbandry practices in Madi Valley, Chitwan National Park, Nepal. *Environmental Conservation*, **36**, 338–47.

Gurung, B., Smith, J.L.D., McDougal, C., et al. (2008) Factors associated with human-killing tigers in Chitwan National Park, Nepal. *Biological Conservation*, **141**, 3069–78.

He, G., Chen, X., Bearer, S., et al. (2009) Spatial and temporal patterns of fuelwood collection in Wolong Nature Reserve: implications for panda conservation. *Landscape and Urban Planning*, **92**, 1–9.

He, G., Chen, X., Liu, W., et al. (2008) Distribution of economic benefits from ecotourism: a case study of Wolong Nature Reserve for Giant Pandas in China. *Environmental Management*, **42**, 1017–25.

Homewood, K., Lambin, E.F., Coast, E., et al. (2001) Long-term changes in Serengeti-Mara wildebeest and land cover: pastoralism, population, or policies? *Proceedings of the National Academy of Sciences of the United States of America*, **98**, 12544–49.

Hu, J.C. (1989) *Life of the Giant Panda*. Chongqing University Press, Chongqing, Sichuan, China (in Chinese).

Hull, V., Shortridge, A., Liu, B., et al. (2011) The impact of giant panda foraging on bamboo dynamics in an isolated environment. *Plant Ecology*, **212**, 43–54.

Hull, V., Zhang, J., Zhou, S., et al. (2014) Impact of livestock on giant pandas and their habitat. *Journal for Nature Conservation*, **22**, 256–64.

Hull, V., Zhang, J., Zhou, S., et al. (2015) Space use by endangered giant pandas. *Journal of Mammalogy*, **96**, 230–36.

Karki, J.B., Pandav, B., Jnawali, S.R., et al. (2013) Estimating the abundance of Nepal's largest population of tigers *Panthera tigris*. *Oryx*, **49**, 150–56.

Kenney, J., Allendorf, F.W., McDougal, C., and Smith, J.L.D. (2014) How much gene flow is needed to avoid inbreeding depression in wild tiger populations? *Proceedings of the Royal Society B: Biological Sciences*, **281**, 20133337.

Lande, R. (1993) Risks of population extinction from demographic and environmental stochasticity and random catastrophes. *The American Naturalist*, **142**, 911.

Laurie, A. (1982) Behavioural ecology of the greater one horned rhinoceros (*Rhinoceros unicornis*). *Journal of Zoology*, **196**, 307–41.

Li, Y., Viña, A., Yang, W., et al. (2013) Effects of conservation policies on forest cover change in giant panda habitat regions, China. *Land Use Policy*, **33**, 42–53.

Linderman, M.A., An, L., Bearer, S., et al. (2006) Interactive effects of natural and human disturbances on vegetation dynamics across landscapes. *Ecological Applications*, **16**, 452–63.

Liu, J., An, L., Batie, S.S., et al. (2005) Beyond population size: examining intricate interactions among population structure, land use, and environment in Wolong Nature Reserve (China). In B. Entwisle and P.C. Stern, eds., *Population, Land Use, and Environment: Research Directions*, pp. 217–37. The National Academies Press, Washington, DC.

Liu, J., Dietz, T., Carpenter, S.R., et al. (2007a) Complexity of coupled human and natural systems. *Science*, **317**, 1513–16.

Liu, J., Dietz, T., Carpenter, S.R., et al. (2007b) Coupled human and natural systems. *Ambio*, **36**, 639–49.

Liu, J., Hull, V., Batistella, M., et al. (2013a) Framing sustainability in a telecoupled world. *Ecology and Society*, **18**, 26.

Liu, J., Ickes, K., Ashton, P.S., et al. (1999a) Spatial and temporal impacts of adjacent areas on the dynamics of species diversity in a primary forest. In D. Mladenoff and W. Baker, eds., *Spatial Modeling of Forest Landscape Change: Approaches and Applications*, pp. 42–69. Cambridge University Press, Cambridge, UK.

Liu, J., Li, S., Ouyang, Z., et al. (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America*, **105**, 9477–82.

Liu, J., Linderman, M., Ouyang, Z., et al. (2001) Ecological degradation in protected areas: the case of Wolong Nature Reserve for giant pandas. *Science*, **292**, 98–101.

Liu, J., Ouyang, Z., Tan, Y., et al. (1999b) Changes in human population structure: implications for biodiversity conservation. *Population and Environment*, **21**, 45–58.

Liu, J., Ouyang, Z., Taylor, W.W., et al. (1999c) A framework for evaluating the effects of human factors on wildlife habitat: the case of giant pandas. *Conservation Biology*, **13**, 1360–70.

Liu, J., Ouyang, Z., Yang, W., et al. (2013b) Evaluation of ecosystem service policies from biophysical and social perspectives: the case of China. In S.A. Levin, ed., *Encyclopedia of Biodiversity* (second edition), vol. **3**, pp. 372–84. Academic Press, Waltham, MA.

Liu, J. and Viña, A. (2014) Panda, plants, and people. *Annals of the Missouri Botanical Garden*, **100**, 108–25.

Liu, W., Vogt, C.A., Luo, J., et al. (2012) Drivers and socioeconomic impacts of tourism participation in protected areas. *PLoS ONE*, **7**, e35420.

Massey, D.S., Axinn, W.G., and Ghimire, D.J. (2010) Environmental change and out-migration: evidence from Nepal. *Population and Environment*, **32**, 109–36.

Matthews, S.A., Shivakoti, G.P., and Chhetri, N. (2000) Population forces and environmental change: observations from western Chitwan, Nepal. *Society and Natural Resources*, **13**, 763–75.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., et al. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853–58.

Nagendra, H., Karmacharya, M., and Karna, B. (2005) Evaluating forest management in Nepal: views across space and time. *Ecology and Society*, **10**, 24.

Nagendra, H., Pareeth, S., Sharma, B., et al. (2008) Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology*, **23**, 41–54.

Nepal Central Bureau of Statistics (2012) *National Planning Comission Secretariat, Government of Nepal*. https://sites.google.com/site/nepalcensus.

Nowell, K. (2012) Wildlife Crime Scorecard: Assessing compliance with and enforcement of CITES commitments for tigers, rhinos and elephants. WWF Report. http://awsassets.panda.org/downloads/wwf_wildlife_crime_scorecard_report.pdf.

Ostrom, E., Burger, J., Field, C.B., et al. (1999) Revisiting the commons: local lessons, global challenges. *Science*, **284**, 278–82.

Pan, W., Lü, Z., Zhu, X.J., et al. (2001) *A Chance for Lasting Survival*. Beijing University Press, Beijing, China (in Chinese).

Parker, D.C., Manson, S.M., Janssen, M.A., et al. (2003) Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annals of the Association of American Geographers*, **93**, 314–37.

Rindfuss, R.R., Entwisle, B., Walsh, S.J., et al. (2008) Land use change: complexity and comparisons. *Journal of Land Use Science*, **3**, 1–10.

Sanderson, E., Forrest, J., Loucks, C., et al. (2006) *Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015*. The technical assessment. WCS, WWF, Smithsonian, and NFWF-STF, New York–Washington, DC.

Schaller, G.B., Hu, J., Pan, W., and Zhu, J. (1985) *The Giant Pandas of Wolong*. University of Chicago Press, Chicago, IL.

Slovic, P. (1987) Perception of risk. *Science*, **236**, 280–85.

Smith, J.L.D., Ahearn, S.C., and McDougal, C. (1998) Landscape analysis of tiger distribution and habitat quality in Nepal. *Conservation Biology*, **12**, 1338–46.

Spiteri, A. and Nepal, S.K. (2008) Distributing conservation incentives in the buffer zone of Chitwan National Park, Nepal. *Environmental Conservation*, **35**, 76–86.

Stræde, S. and Helles, F. (2000) Park-people conflict resolution in Royal Chitwan National Park, Nepal: buying time at high cost? *Environmental Conservation*, **27**, 368–81.

Stræde, S. and Treue, T. (2006) Beyond buffer zone protection: a comparative study of park and buffer zone products' importance to villagers living inside Royal Chitwan National Park and to villagers living in its buffer zone. *Journal of Environmental Management*, **78**, 251–67.

Tuanmu, M.-N., Viña, A., Roloff, G.J., et al. (2011) Temporal transferability of wildlife habitat models: implications for habitat monitoring. *Journal of Biogeography*, **38**, 1510–23.

Turner, B.L., Kasperson, R.E., Matson, P.A., et al. (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, **100**, 8074–79.

UNEP/WCMC (2011) *Royal Chitwan National Park, Nepal*. United Nations Environment Programme/World Conservation Monitoring Centre. http://www.unep-wcmc.org/.

Viña, A., Bearer, S., Chen, X., et al. (2007) Temporal changes in giant panda habitat connectivity across boundaries of Wolong Nature Reserve, China. *Ecological Applications*, **17**, 1019–30.

Viña, A., Chen, X., McConnell, W.J., et al. (2011) Effects of natural disasters on conservation policies: the case of the 2008 Wenchuan Earthquake, China. *Ambio*, **40**, 274–84.

Viña, A., Tuanmu, M.N., Xu, W., et al. (2010) Range-wide analysis of wildlife habitat: implications for conservation. *Biological Conservation*, **143**, 1960–69.

Wyler, L.S. and Sheikh, P.A. (2008) *International Illegal Trade in Wildlife: threats and US policy*. Congressional Research Service, Library of Congress, Washington, DC.

Yang, W., Liu, W., Viña, A., et al. (2013) Performance and prospects on payments for ecosystem services programs: evidence from China. *Journal of Environmental Management*, **127**, 86–95.

Yong, Y., Liu, X., Wang, T., et al. (2004) Giant panda migration and habitat utilization in Foping Nature Reserve, China. In D. Lindburg and K. Baragona, eds., *Giant Pandas: Biology and Conservation*, pp. 159–69. University of California Press, Berkeley, CA.

Zhang, Z., Sheppard, J.K., Swaisgood, R.R., et al. (2014) Ecological scale and seasonal heterogeneity in the spatial behaviors of giant pandas. *Integrative Zoology*, **9**, 46–60.